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Geophysical Survey and Archaeological Excavations in the Neolithic and Bronze-Age Settlement of La Dou (Girona, Spain) A combined Approach to a New Site

Prospection géophysique du site néolithique de l'Âge du bronze de La Dou (Girona, Espagne)

Roger Sala[a], Robert Tamba[b], Ekhine Garcia-Garcia[c], Gabriel Alcalde[d], Vanessa Navarrete[e], Jordi Revelles[e], Maria Saña[e] and Rafael Rosillo[e]

Abstract: This paper presents the results of the investigations carried out from 2009 to 2013 in the multi-period archaeological site of La Dou (Sant Esteve d'en Bas, Girona, Catalonia). The authors expose the strategy applied to create the surveys and results of the excavations conducted to verify and date the detected features. The site was discovered in 2005 in a rescue excavation due to the building of a road, revealing a group of firing pits and other stratigraphic remains of a rare Neolithic, open-air settlement, dated from the 5th millennium BC. In 2009, a team of archaeologists from the Universitat Autonoma de Barcelona (UAB) created a project to expand the investigations to the cultivation fields surrounding the first findings. A magnetic survey was used to locate new archaeological remains and delimit the possible extents of the site. The results revealed a complex magnetic map that included several groups of anomalies interpreted as possible archaeological remains in an area of circa 2.4 ha. The attention of the team was then focused on a possible ditch detected in the survey and that was partially excavated. The excavation results and the C14 analysis expanded the chronology of the site until the Bronze Age, revealing an uncommon settlement that is still the object of investigations.

Résumé : *Cet article présente les résultats de la recherche menée entre 2009 et 2013 sur le site archéologique multi-période de La Dou (Sant Esteve d'en Bas, Girona, Catalogne). Les auteurs exposent la stratégie d'exploration appliquée et les résultats des fouilles menées pour vérifier et dater les structures détectées. Le site a été découvert en 2005 lors de fouilles préventives réalisées en raison de la construction d'une route. Elles ont révélé un groupe de structures de combustion et d'autres vestiges stratigraphiques d'un site Néolithique daté du 5e millénaire avant notre ère. En 2009, une équipe d'archéologues de l'Universitat Autonoma de Barcelona (UAB) a créé un projet visant à étendre la recherche aux champs entourant les premières structures découvertes. Une prospection magnétique a été réalisée afin de localiser de nouveaux vestiges archéologiques et de délimiter l'étendue du site. Les résultats ont révélé une carte magnétique complexe qui comprend plusieurs groupes d'anomalies interprétées comme de possibles vestiges archéologiques dispersés sur une étendue d'environ 2,4 ha hectares. L'attention de l'équipe a été portée sur une structure interprétée comme un possible fossé et partiellement fouillée. Les résultats des fouilles et des datations au carbone 14 ont permis d'élargir la chronologie du site à l'Âge du bronze et de révéler un établissement humain rare faisant toujours l'objet de recherches.*

Keywords: Neolithic, Magnetometry, Ground-Penetrating Radar, Bronze-Age ditch, GIS, geophysical survey methodology, Garrotxa Volcanic Area.

Mots clés: *Néolithique, magnétométrie, géoradar, fossé de l'Âge du Bronze, SIG, méthodologie de prospection géophysique, région volcanique de la Garrotxa*

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1. Introduction

The Neolithic period led to the establishment of the first farming communities in permanent open-air settlements. These first open-air settlements generally are comprised of non-preserved wooden structures in dry areas such as the Iberian Peninsula. This implies a low potential of archaeological remains and adds difficulties in the process of finding new archaeological sites. Given the irregular and dispersed occupation of the territory in these early stages of farming communities, the identification of the limits of one archaeological site is a hard task to do with traditional archaeological methodology.

Geophysical surveys have been recognized over the last couple of decades as a useful tool to detect and describe new archaeological sites (Sala *et al.*, 2012). The application of archaeological Geophysics in the particular case of La Dou site is an example of how the ability to explore large areas around a given site or feature widens the focus of archaeological investigations.

The site of La Dou is located in a current crop field in La Vall d'en Bas (Girona, Spain) and consists of one of the earliest open-air settlements in the area, with an occupation around the 5th millennium cal. BC (4800-4300) in the context of the Late Early Neolithic. The project of archaeological research focused on the site of La Dou started in 2006, and at the moment, 770 m^2 have been excavated. The work carried out in this site allowed the documentation of an open-air settlement characterized by a dispersed occupation in the territory, findings in the area show a concentration of fire pits (all of them homogeneous, showing 1 m diameter, 0.2 to 0.3 m of depth), structures cut into the subsoil, evidence of some post holes (difficult to identify due to bad preservation of organic matter and very homogeneous sediments); and then, empty areas where only dispersed lithic or pottery remains are recovered.

Due to the dispersed and spatially irregular occupation of the area and the difficulties of identifying the limits of the site and also the production areas around combustion structures, the UAB team decided to integrate geophysical prospection within the project. The objectives of the integration of archaeological excavation and geophysical prospection can be divided in two groups: a) Archaeological objectives: applying this methodology in order to detect archaeological structures, as a guide to decide where to excavate. In this sense, geophysics can help us in our purpose to know the social organization of the space and to delimitate the archaeological site. b) A methodological objective. The application of archaeological geophysics is not common for these chronologies in the Iberian Peninsula, compared with historical periods and sites built by means of architecture in stone (Sala *et al.*, 2013). Indeed, the imaging and characterization of features such as post-holes, pits, ditches or hearths have been studied using magnetic surveys in central and northern Europe and British Islands from decades. These studies included not only comprehensive descriptions of sites (Ard *et al.*, 2015), but also interesting methodological approaches. Studies comparing soil analysis, excavation data and magnetic measurements aimed to understand the configuration of magnetic expression of archaeological features (Ghesquière *et al.*, 2011; Nowaczinski *et al.*, 2012).

The use of geophysics in general is less frequent in the North East of Iberian Peninsula than in other parts of Europe. In addition, the particular climatic, geomorphological and environmental conditions of this Mediterranean region, and the cultural and technological particularities of local protohistoric settlements configure an interesting subject for new combined archaeological and geophysical studies.

As it will be seen, the survey strategy, originally planned to detect and map the possible extents of Neolithic firing pits, was modified after the findings of new features from other chronologies.

2. Environmental settings

The archaeological site of La Dou is placed 500 m to the east of the village Vall d'en Bas, in the province of Girona (Catalonia, Spain).

The known extent of the site lay in a group of cultivation fields, in the closing of a small valley of 2.5 km formed by the Ridaura River (Fig. 1).

The local geology at the bottom of the valley consists in alluvial and colluvial deposits containing clayey and gravel layers, with a dominance of clayey soils in the site area. The proximity of the Garrotxa volcanic area, about 5km northwards from the site was also considered relevant, as the possible presence of volcanic materials in the gravels could have a part in the configuration of magnetic response of the site.

The cultivation fields where the site was delimited are closed at the North by the road C-152a and the Ridaura river to the South, configuring a smooth slope to the river.

The aerial imagery sequence of the site, available from the Cartographic Institute of Catalonia (ICC) was also examined in order to locate possible earth movements or crop marks from first data of 1956. The images showed only changes in the field divisions, but no other remarkable vegetation anomalies were noted.

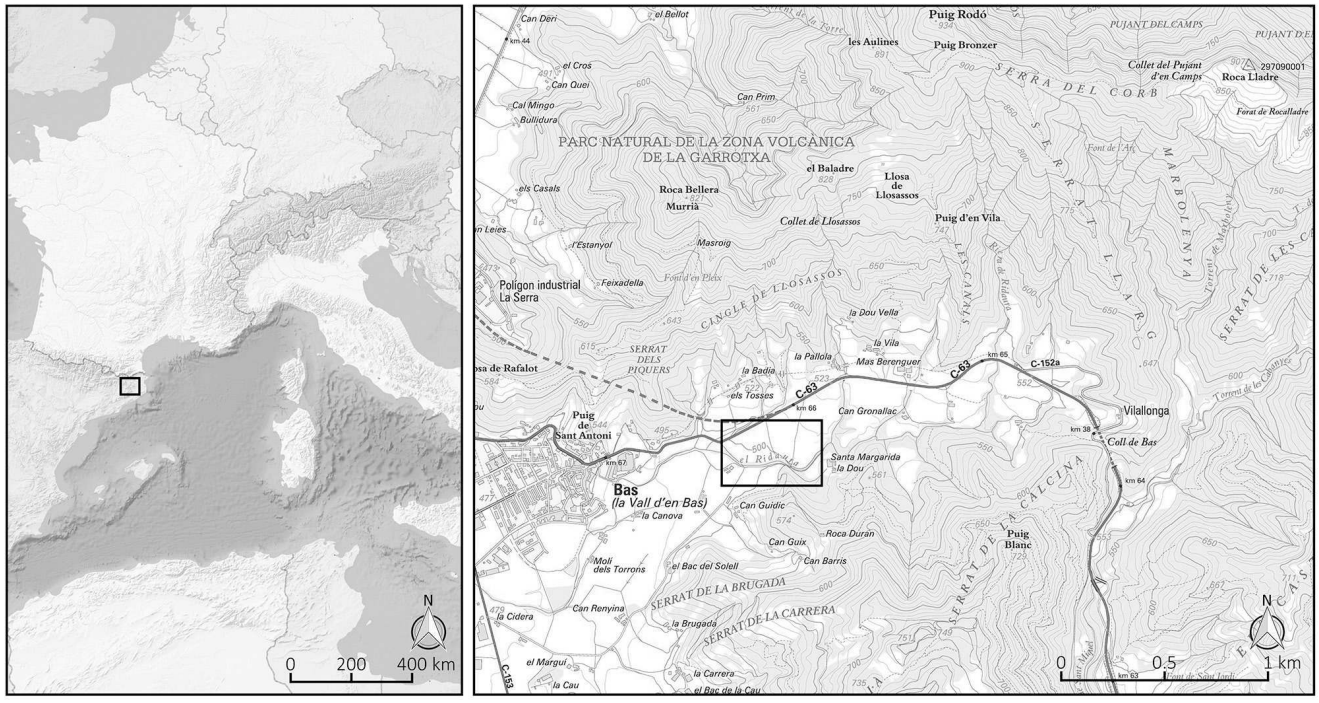

Figure 1: Location of the site of La Dou in southern Europe (left) and in the region of La Garrotxa (right).
Figure 1: Emplacement du site de La Dou au sud de l'Europe (gauche) et dans la région de La Garrotxa (droite).

3. Methodologies

Magnetic survey 2009

Archaeological geophysics offer different tools and multiple survey strategies suitable to characterize an archaeological site (Sala *et al.*, 2016). The success of a geophysical survey (to offer valuable information about a given site) depends in a good part on an accurate survey strategy.

Starting from an archaeological question, that is, to locate in the surrounding fields other possible firing pits (similar to the ones unearthed in the rescue excavation of 2005) the survey was planned, taking into account the environmental conditions of the site and the expected geophysical properties of the archaeological target.

The local geology and surface covering offered good conditions for GPR, resistivity or magnetic methods, but the physical properties of firing pits, presumably configuring high-contrast, and North-South polarized magnetic anomalies, made evident that the magnetic survey would be the best choice (Sala *et al.*, 2012).

As the information given from the rescue excavation of 2005 was partial and restricted to the road building project, the survey project established a survey area of 20,000 m^2 southwards from the road, to ensure a wider context for possible findings. The magnetic survey was carried out in December of 2009, using a Bartington G-601 dual fluxgate gradiometer system. The survey spatial resolution was established in 0.25 × 0.5 m or 8 readings per square meter. The total explored area was of 24,448 m^2.

As the applied system is a magnetic gradiometer, measuring the gradient of the vertical component of magnetic field, the readings correspond to a variation from a local, conventional zero value. Then, the readings express the variations up or down from this zero value, that we will refer in the text as positive relative values or negative relative values.

The raw data were processed using Geoplot 3.0 software. The processing sequence consisted in a positioning correction of readings (stagger), a line mean correction (zero-mean line), and a low-pass filter of 2 × 1 cells (1 m). The resulting dataset was finally interpolated in the x direction to obtain a regular cell-size of 0.25 × 0.25m to smooth visually the data plots.

Excavation

In 2010 and 2011 trenches (Sectors I and K) of 20 m² were excavated to verify the geomagnetic anomalies. In 2013, a bigger sector (M, 50 m²) (Fig. 2) was excavated in order to document the ditch that was insinuated after geophysical surveys and the excavation in 2010-2011.

GPR survey 2012

After the first excavations of 2010 and 2011 centered on the group of anomalies 4 described in the initial magnetic survey, the interpretation of the feature as a possible ditch was confirmed (Fig. 3). A further step in the comprehension of function and delimitation of the structure was needed to plan new excavations. A GPR survey was planned over the north half of the ditch in order to obtain new information on its structure and its geometry and select a wider excavation area.

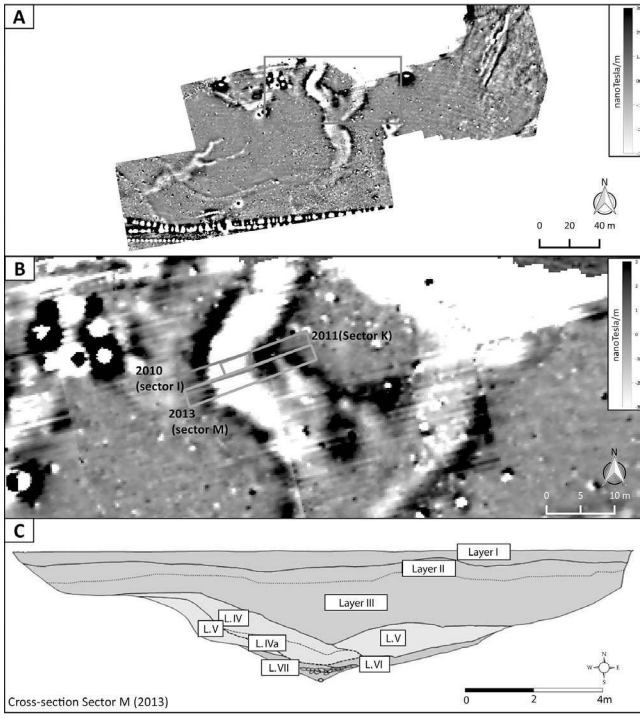

Figure 2: (See colour plate XIII) Excavations of the ditch. A magnetic map. B shows the position of trenches carried out in 2010, 2011 and 2013 on the magnetic gradient map. C stratigraphic cross-section obtained from the excavation of 2013.
Figure 2 : (Voir planche couleur XIII) Description des fouilles du fossé. A carte magnétique. B Position des tranchées d'excavations réalisées en 2010, 2011 et 2013 sur la carte de gradient magnétique. C Coupe stratigraphique des fouilles réalisées en 2013.

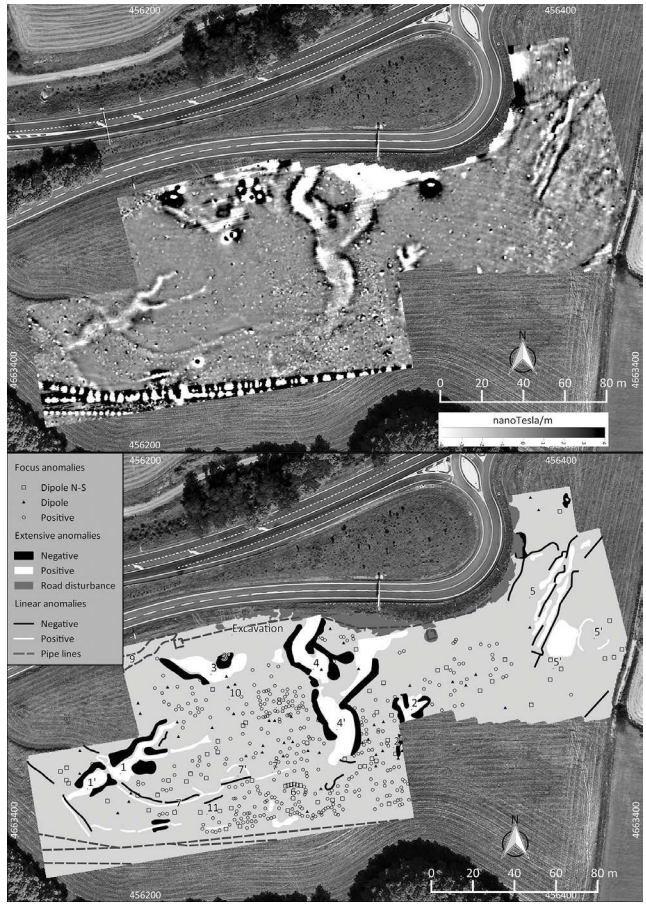

Figure 3: (See colour plate XIV) Magnetic map and interpretation. (top) Magnetic gradient map at +/-3 nT/m. Black for negative values. Background aerial photograph www.icgc.com. (bottom) Interpretation diagram.
Figure 3 : (Voir planche couleur XIV) Représentation et interprétation des données magnétiques. (en haut) Carte de gradient magnétique ajustée à +/-3 nT/m, -3 nT/m en noir et +3 nT/m en blanc. Fond: photographie aérienne de l'ICGC, www.icgc.com. (en bas) Diagramme interprétatif des données.

The total depth of the ditch shown in the excavation trenches was 3M. The clayey soil and moderate moisture shown in the excavations indicated a significant reduction in the depth range of GPR systems that could not reach the bottom of the ditch. Nevertheless, obtaining data corresponding to shallower parts of the ditch and its enclosure structures was considered as helpful information to optimize further excavations.

The data collection was carried out in January of 2013, covering an area of 483 m². The data were acquired using the IDS Hi Mod system, with a dual antenna of 200 MHz and 600 MHz. Time windows of 90 and 60 nanoseconds were selected for the 200 MHz and 600 MHz data respectively. The spatial resolution of the survey was set to 0.02×0.2m,

acquiring the profiles in the direction perpendicular to the longest side of the ditch.

The raw data were processed to eliminate system noise and unwanted interferences. The first step consisted in a gaining and phase correction on a range of 28 samples. Secondly, a background filter was applied (Annan, 2009). A third phase of data processing used the GPR-Slice software to generate a time-slice sequence of both datasets and secondary 3d visualizations (pseudo-sections, isosurfaces). The resulting time-slice sequence was expressed in depth ranges after estimating a propagation velocity of EM pulses of 0.09 m/ns from hyperbolae geometries in the data. (Conyers & Lucius, 1996).

Data interpretation and GIS

The open source QuantumGis software was used as a basic information exchange tool between the parties of the project. Geophysical survey data consists of soil property maps that must be interpreted, communicated, and finally translated to possible archaeological features.

GIS systems are a powerful tool for this purpose, as they allow analyze geophysical data and interpret them in the context of other significant data, such as aerial imagery, multispectral imagery, local topography, geology or excavation data. All cartographical data was obtained from public archives of ICC (Institute Cartografic de Catalunya). After interpretation, georeferenced, coded interpretation diagrams were produced to communicate simplified survey results and compare it with excavation data.

The magnetic data interpretation was made from a first classification of detected magnetic anomalies, dividing them as focus, linear or extensive. Each of these categories was also sub-divided depending on their relative polarity. Interpretation diagrams were produced based on this classification. The groups of anomalies were also labeled with numbers to allow an easier description (Fig. 3).

The later GPR survey carried out in 2012 was also included in the GIS system of the project. The output format of GPR survey was a sequence of time-slices, corresponding to increasing depth. In order to produce more comprehensible graphic information, a depth interpretation diagram was produced. It was based on vectorial simplification of detected anomalies for each time-slice, to express how these anomalies change with depth.

4. Results

Magnetic survey results 2009

The magnetic map obtained from the processing (Fig. 3) shows 11 groups of anomalies which were considered relevant, and other three anomaly groups related with modern features: pipes and road disturbance indicated in blue and an excavation trench conducted in 2005 labeled “Excavation”.

Group 1 is formed by extensive anomalies of both positive and negative relative magnetic values. The disposition of the anomalies in the same direction of the descending slope and the wider form of 1’ are interpreted as a product of a possible hydrological event. Heavy rain episodes in short times are not rare in the site region during autumn and spring, producing local floods. This kind of sudden precipitation could produce deep torrent strips in the fields if they are sloped.

Despite an incomplete detection, the anomaly group 2 was interpreted in the same sense because of its similarity in terms of geometry and disposition respect to the field slope.

Group 3, in the Northwest of the survey area was more complex. It includes a main anomaly of positive relative values (from 2.5 to 5nT/m) 25 m long with a variable width. A secondary anomaly of negative values called 3’ shows values of -3nT/m in an area of 6 × 6m at North of group 3. This group of anomalies was interpreted as a possible anthropic related feature, but neither its shape nor its values gave more information to offer a more concise interpretation.

The most interesting feature described in the survey was group 4, formed by a vaguely rectangular shape of 38×25 m. This rectangular shape consists in a fringe of positive magnetic values (3 to 9 nT/m) 5.5 m wide, surrounded by a halo of negative relative values. An area placed at the south of the group shows a decrease in magnetic contrast. The Northeast limit of the feature is not clear as it gets blurred by the magnetic influence of the road’s metal fences. A secondary anomaly group called 4’ is placed at the south of 4, showing an irregular shape of 30X12 m. As in the case of 4, the central anomaly shows positive relative values (2 to 6 nT/m) weaker in south direction, and a negative halo. Group 4 was interpreted as possible ditch remains due to its geometry, its characteristic positive magnetic response (Schmidt, 2007) and its higher values in the center of the fringe. The secondary group 4’ was interpreted as a possible secondary structure related to the ditch but could also be explained by hydrologic features as groups 1 and 2.

At the east of the survey area a new group of anomalies called 5 occupies an extension of circa 3,000 m². It consists of a group of linear anomalies going from Northeast to Southwest of both polarities, measuring 51 m long, sur-

rounded at the south by an area with a predominance of positive values called 5'. The eastern limit of 5' also shows some isolated dipoles and a group of slightly lower magnetic values. The group of linear features appear to reproduce at least 3 parallel fringes of positive relative values (3nT/m to 8 nT/m), and a secondary halo of negative values of -1nT/m to 5 nT/m. The 5' sub-group does not show clear shapes that could be identified as anthropic objects, only weak negative areas and apparently random higher value areas. Although the linear features could be interpreted as small ditches or even buried old field limits, the interpretation of this entire area is unsure. The higher magnetic values of the 5' group and the parallel disposition of linear features of group 5 could also be interpreted as related to some kind of cultivation event, and should be verified by excavation.

An interesting concentration of nearly 250 weak, focus anomalies was also detected in the center and south of the survey area. Most of these small peaks show positive relative values. In the same area, dipoles were also detected and were identified as small iron objects and fire-related dipoles. Examining in detail the geometry and disposition of these anomalies, two significant groups were labeled as anomaly groups 6 and 8. Group 6 consists of 10 small focus anomalies (6 dipoles, 4 positive), forming an apparent linear feature. Group 8 consists of a group of nearly 30 positive focus anomalies placed southwest of group 4. Although they do not show a clear geometric pattern, some anomaly alignments can be detected. Groups 6 and 8 and the rest of positive focus anomalies spread in the area have multiple interpretations. At first sight, the similar values and apparent alignments of groups 6 and 8 suggest a possible anthropic origin, as it could be post-holes (Herbich & Tunia, 2009). Another interpretation could consist of associating the focus anomalies with high contrast geologic materials (basalts) in the context of the river terrace.

Group 7 consists of a curved linear feature in the east-west direction. It was identified as a possible old field division based on the analysis of the 1956 aerial photograph.

Group 9 was delimited at the northwest of the survey area. It was identified as a fringe of anomalous response with high contrast readings of both polarities. This group was interpreted as a possible modern feature related with the building of the road.

Groups 10 and 11 consist of high contrast dipoles, interpreted as iron objects.

Archaeological trenches 2010-2011

The excavation of two 20 m^2 trenches in 2010-2011 allowed the identification of archaeological layers infilling a cut in the fluvial terrace (Fig. 2). The archaeological layer was characterized by a high amount of organic matter and combustion residues. In the base of this level and above the geological substrate, charred wooden elements were found, probably related with burnt wooden structures. Among the archaeological remains, pottery was the most represented. ^{14}C dates confirmed the hypothesis of a Late Bronze Age occupation (1260-920 cal BC) previously made in base of pottery decoration.

GPR survey results 2012

The two datasets obtained from the GPR survey were examined in order to study in which aspects they could complement the magnetic data. The highly clayey soil and terrain moisture produced an evident attenuation on the 600 MHz GPR dataset, which was discarded because of the shorter depth range of the data.

The 200 MHz dataset hardly reached 1.5 m-1.7 m depth, but it was considered a better base for further processing and visualization despite its lower horizontal resolution.

The resulting time-slice sequence show a superficial layer containing anomalies produced by plough works until a depth of 0.30 m.

The first reflective features identified as inside (B) and outside (Ab-A) the ditch appears at 0,45 m depth (Fig. 4). As can be seen in the cross sections of Fig. 5, B appears as a reflective, flat anomaly, probably produced by the floor levels inside the ditch enclosure. Anomaly group A shows two apparent phases, called Ab for the shallower depths (0.3-0,6 m) and a second deeper layer called A.

Between a depth of 0.6 and 0.8 m, a low reflection interval was interpreted as the homogeneous fillings of the shallower parts of the ditch system (C). At the same depth range, a pipe is detected at the north of the survey area.

In the center of survey area appears an anomaly corresponding to the positions of the trial trenches of 2010-2011.

In deeper data representations, a subtle shrinking of the C fringe could be seen (fig. 4). In the cross sections of Fig. 5 data plots show a region with different response labeled as F corresponding to a decay in reflection. The cross sections also show the ditch itself (E) separated from inner features (B) by an unknown feature (D), than appears in some regions of the inner perimeter.

The reflective response for E could be produced by the coarser materials of the natural refilling of the ditch, probably related with higher levels (A, and B).

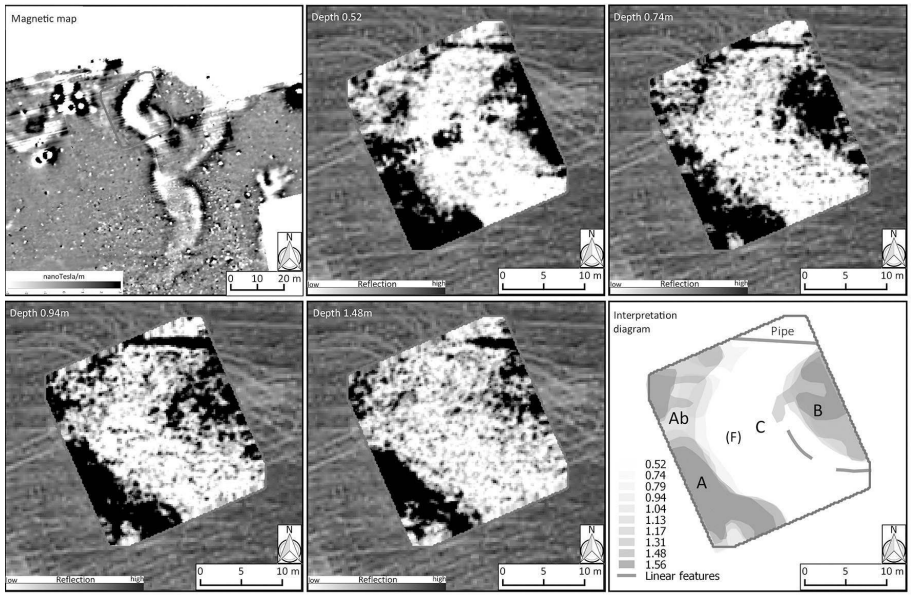

Figure 4: (See colour plate XIV) Magnetic gradient map of group 4, GPR survey depth-slice sequence and interpretation diagram.
Figure 4 : (Voir planche couleur XIV) Carte de gradient magnétique du groupe de structures 4, séquence de cartes des données géoradar de profondeurs successives et diagramme interprétatif.

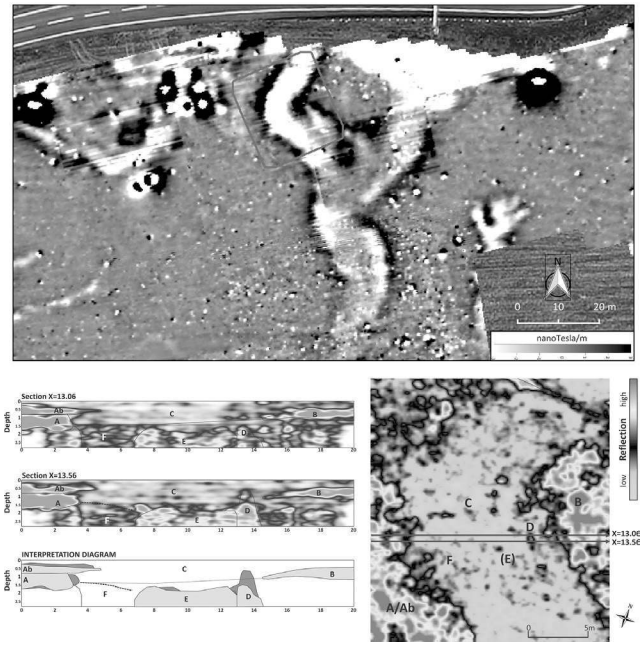

Figure 5: (See colour plate XV) Cross-sections from GPR survey data of group 4 and interpretation diagram.
Figure 5 : (Voir planche couleur XV) Coupes transversales des données géoradar centrées sur le groupe de structures 4 et diagramme interprétatif.

Further excavations (2013)

The Sector M excavation in 2013 provided more information to comprehend this macrostructure, documenting both the east and west limits (Fig. 2), and allowed verifying the stratigraphic approximation offered by GPR data. A cut in the fluvial terrace of 5m width was documented, consistent with previous works in sectors I and K. The stratigraphy is detailed in Table 1 and can be observed in Fig. 2.

Better preservation conditions were documented in the western part of the sector, where two archaeological layers (IV/Iva and VII) were separated by natural layers produced as a result of soil erosion (V and VI). In that sense, geomagnetic, GPR and archaeological data coincide, as shown in the stronger signal in the western part of the structure (Fig. 5). This huge cut in the fluvial terrace would have been produced by strong soil erosion in an imprecise period of the Mid-Holocene, probably related with streams proceeding from the near slopes to the north of the site. This palaeotopography would have been used by Late Bronze Age communities as a limit of the settlement or structures and allowed the preservation of charred wooden structures and a remarkable assemblage of archaeological remains: construction materials, bronze tools, jewels, "prestige" pottery (Fig. 2).

5. Discussion-Conclusion

The initial target of the survey, to locate Neolithic firing pits, was changed after the first magnetic survey that showed a number of anomaly groups which could be related to different causes and chronologies.

In addition, the lack of archaeological information around open-air prehistoric settlements in the region represents a challenge in the interpretation of geophysical data from la

Layer	Description
I	Agricultural soil
II	Yellowish silts without archaeological remains
III	Greyish silts above IIIa and IV
IIIa	Greyish silts and sands with presence of charcoal. Thicker in the northern part of the sector, absent in the south cross section.
IV	Black silty layer. High amount of archaeological remains and charcoal.
IVa	Black silty layer. Consists of the base of the level IV. Covering level V in the east and level VI in the west.
V	Sandy layer composed by erosion episodes affecting the fluvial terrace. Evidenced in the eastern part of the sector.
VI	Sandy layer composed by erosion episodes affecting the fluvial terrace. Evidenced in the western part of the sector.
VII	Brownish silts and sands with presence of archaeological remains. Presence of big stones. Deposited above the terrace.
VIII	Fluvial terrace. Geological substrate.

Table 1: Description of the stratigraphic layers in Sector M.
Tableau 1 : Description stratigraphique des couches du sector M.

Dou site. This lead the research to a new focus on the site that required additional work based on the archaeological verification of data interpretations.

The excavations of 2010 and 2011 aimed to verify and describe the finding of a possible ditch (anomaly group 4-4'). The two trenches showed a first cross-section of the ditch and revealed a later chronology than the firing pits. Although the shape of the ditch could be easily recognized in magnetic data, there are significant internal variations in magnetic values. Further studies such an extensive excavation and systematic magnetic susceptibility measurements could help to establish the stratigraphical sequency of the settlement and to better understand the magnetic data, such as how burnt materials found in the deeper layers of the ditch contribute to the strength of magnetic gradient values (Linford & Canti, 2001).

The GPR cross-sections offered a view of parts of the shallow ditch-system stratigraphy that still needs to be completed. The most reflective features (A-Ab, B, E) appeared to be coincident with paleo-soils described in the excavation. These layers contained a mix of clay and small gravel that could be responsible of the increase of reflection described in the cross-section (Fig. 4).

The GPR map sequence showed less definition in the northern corner of the ditch. This has been interpreted as a product of a different composition of upper layers of these regions. Again, an extensive excavation may help to understand if this difference is related with a different composition of upper layers or if it comes from a destruction of upper structures by erosion.

The interpretation of some groups of anomalies detected on magnetic data is still hypothetic and need to be verified. In the particular case of weak, positive focus anomalies described in the south half of the survey area, the interpretation remained uncertain. Groups 6 and 8 seem to configure geometric patterns that could point to an anthropic origin, but they represent only a minimum part of the total positive focus anomalies detected. The alternative interpretation of these anomalies as product of high contrast materials related with volcanic activity could not be discarded. Indeed, their position in the lower elevation areas, in the vicinity of Ridaura river could be interpreted as a spread of alluvial materials carried by hydrologic activity.

The eastern area of the survey also showed interesting results. The group 5-5' consists of linear and extensive anomalies that have been interpreted as possible anthropic features, obviously leaving apart its chronology and relation to the ditch complex, since it only will be established by excavation.

The evidence of the Late Bronze Age occupation consists of an exceptional finding in the northeast Iberian Peninsula, as open-air settlements are unknown for this area in this chronology. Furthermore, the evidence of archaeological remains and the evaluation of the limits of the archaeological site, the geophysical survey allowed assessing site formation processes and obtaining palaeoecological data. In that sense, intensive erosion in an imprecise period of the Mid-Holocene produced streams in the area, affecting the conservation of Neolithic structures in the deeper part of the site and providing a palaeotopography used by Late Bronze age communities.

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